Quarantine Security of Bananas at Harvest Maturity Against Mediterranean and Oriental Fruit Flies (Diptera: Tephritidae) in Hawaii

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ABSTRACT Culled bananas (dwarf 'Brazilian', 'Grand Nain', 'Valery', and 'Williams') sampled from packing houses on the islands of Hawaii, Kauai, Maui, Molokai, and Oahu identified specific "faults" that were at risk from oriental fruit fly, *Bactrocera dorsalis* (Hendel), infestation. Faults at risk included bunches with precociously ripened bananas, or bananas with tip rot, fused fingers, or damage that compromised skin integrity to permit fruit fly oviposition into fruit flesh. No Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), or melon fly, *B. cucurbitae* (Coquillett), infestations were found in culled banana samples. Field infestation tests indicated that mature green bananas were not susceptible to fruit fly infestation for up to 1 wk past the scheduled harvest date when attached to the plant or within 24 h after harvest. Recommendations for exporting mature green bananas from Hawaii without risk of fruit fly infestation are provided. The research reported herein resulted in a USDA-APHIS protocol for exporting mature green bananas from Hawaii.

KEY WORDS *Musa acuminata*, tephritid fruit flies, banana, quarantine, trapping

FRUITS AND VEGETABLES grown in Hawaii are subject to federal quarantine regulations because *Bactrocera latifrons* (Hendel), *Ceratitis capitata* (Wiedemann) (Mediterranean fruit fly), *B. cucurbitae* (Coquillett) (melon fly), and *B. dorsalis* (Hendel) (oriental fruit fly) are established on all islands with commercial agriculture (Anonymous 1998). Commercial bananas, *Musa acuminata* (Colla), grown in Hawaii are known hosts of Mediterranean and oriental fruit fly when ripe, but are not hosts in nature at the mature green stage of harvest maturity (hereafter referred to as green bananas) (Umeya and Yamamoto 1971, Armstrong 1983). Bananas are not listed as hosts of *B. latifrons*, a species that prefers solanaceous fruit hosts (Liquido et al. 1994), or melon fly, a species that prefers cucurbitaceous fruit hosts (Anonymous 1986). Green bananas, considered a nonhost for Mediterranean fruit fly, were exported to the United States mainland before oriental fruit fly became established in Hawaii in 1945. After oriental fruit fly was established, a quarantine fumigation with ethylene dibromide was required for export bananas (Akamine 1965, Anonymous 1976). Ethylene dibromide was an unsatisfactory treatment for export bananas because the fumigant induced ripening and reduced shelf life. Banana exports from Hawaii, which declined sharply after 1945, ceased altogether after the registration for ethylene dibromide was rescinded in 1984 (Ruckelshaus 1984).

Increased banana production in Hawaii during the 1990s met the local market demand, and the industry began developing strategies for supplying niche markets on the U.S. mainland and in the Pacific Basin (Richard Ha, HI, Banana Industry Association, personal communication). The major commercial bananas produced in Hawaii include the dwarf 'Brazilian', 'Grand Nain', 'Valery' (also called 'Taiwan'), and 'Williams' bananas. Grand Nain, Valery, and Williams are grouped together in a general classification known as Cavendish bananas (Robinson 1966, Simmonds 1966, University of Hawaii 1990). The term "Cavendish" is used herein when appropriate to reduce repetition of the three cultivar names (Grand Nain, Valery, and Williams).

The dwarf Brazilian is a mutant originating from Brazil where it is known as the 'Santa Catarina Prata'. The University of Hawaii introduced the dwarf Brazilian into Hawaii in 1979 (University of Hawaii 1990). By 1996, commercial production of standard Brazilian, which grows to ≈8 m, was replaced by the dwarf Brazilian, which grows to ≈6 m. The shorter dwarf Brazilian is easier to manage, less susceptible to lodging, and the bunches, which grow closer to the ground, are easier to care for and harvest (University of Hawaii 1990). Armstrong (1983) showed that green standard Brazilian, Valery, and Williams bananas with intact, undamaged skin were not hosts for Mediterranean fruit fly, melon fly, or oriental fruit fly in both plantation and laboratory infestation studies. The dwarf Brazilian was not used in the Armstrong (1983) research because no commercial production was available at the time.

Cavendish bananas, the main banana group exported from Central and South American countries, remain green during shipment to market, where they are ripened with ethylene gas treatment. Although

Cavendish bananas ripen over time without ethylene gas treatment, the treatment promotes uniform fruit ripening. Brazilian bananas ripen more rapidly and uniformly than Cavendish bananas; therefore, ethylene gas treatment is not used (Akamine 1965, Robinson 1966, Delmonte Fresh Produce 1992). In addition to more rapid ripening, the occurrence of precocious ripening (advanced ripening of one or more fruits on a bunch of green fruits attached to the plant) occurs more in Brazilian bananas than in the Cavendish group (Richard Ha, Hawaii Banana Industry Association, personal communication).

Cavendish bananas are not considered Mediterranean fruit fly hosts when green (Umeya and Yamamoto 1971, Anonymous 1996) and have been imported into the United States for many decades from Central and South America. Mediterranean fruit fly is found in the banana-growing areas of Central and South America, whereas both Mediterranean fruit fly and oriental fruit fly are found in Hawaii. Japan does not consider green bananas a host for either Mediterranean or oriental fruit fly and allows importation of bananas from Central and South America, Southeast Asia, and Hawaii with the restriction that all fruit arriving must be green with no appearance of ripening (Anonymous 1996).

A site survey in Hawaii County in 1996 by USDA-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (APHIS-PPQ) personnel, Agricultural Research Service (ARS) personnel, and members of the Hawaii Banana Industry Association identified several issues, especially for dwarf Brazilian bananas, that had to be resolved before APHIS-PPQ could develop a quarantine export protocol for green bananas (Miller and Chang 1998). Specifically, APHIS-PPQ requested that ARS initiate research to clarify the host status of bananas for Mediterranean and oriental fruit fly in Hawaii by determining the following: (1) whether these species of fruit flies occur in banana plantations and packing houses; (2) which types of damage to the fruit that can occur during the production of dwarf Brazilian, Grand Nain, Valery, and Williams bananas are at risk of fruit fly infestation; (3) whether green dwarf Brazilian bananas are a host before harvest; (4) whether green dwarf Brazilian bananas in bunches that have some precociously ripened fingers are at risk of infestation; (5) whether green dwarf Brazilian bananas that are 1 wk past the scheduled harvest date and remaining on the plant are at risk of infestation; (6) whether green dwarf Brazilian bananas could become infested in areas where large populations of Mediterranean fruit fly naturally occur; (7) whether fruit fly eggs deposited in green dwarf Brazilian bananas can survive after harvest; (8) elapsed time after harvest before green dwarf Brazilian bananas can become infested; and (9) whether fruit surface color or fruit firmness measured by simple analytical methods could be used to replace visual observation by inspectors to determine the recency of harvest of green dwarf Brazilian bananas at the packing house. Research emphasis was placed on green dwarf Brazilian bananas because of the ripening characteristics of this cultivar. In addition to research with fruit flies, APHIS-PPQ requested that ARS examine all bananas used for test purposes to detect other insects that could pose a quarantine problem if found on exported bananas. Reported herein are the results of research carried out from July 1996 to August 1998 to resolve quarantine security issues regarding the export of green Brazilian, Grand Nain, Valery, and Williams bananas from Hawaii. As a result of this research, APHIS-PPQ developed a protocol for exporting mature green bananas from Hawaii.

Materials and Methods

Banana Maturity Identification. Identification of banana maturity was done by visual matching of the external banana color compared with maturity designations of a standard banana ripening chart. All banana ripening color charts, such as those available from United Fruit Sales Corporation, Dole Corporation, or Delmonte Fresh Fruit Corporation, are similar and are used universally by the banana industry to identify fruit maturity. The seven stages of ripeness based on external fruit coloration are as follows: 1, mature green; 2, green with a trace of yellow; 3, more green than yellow; 4, more yellow than green; 5, green tip only; 6, all yellow; and 7, yellow flecked with brown. The term "green" used herein to define banana ripeness, refers to the mature green stage 1 designated by the standard banana ripening charts. However, greenness is relative to the observer because color judgment is influenced by the observer's age, color aptitude, and quality of color vision, and by the light-source viewing conditions (Mackinney and Little 1962). Other considerations affecting color judgment include age and condition of the banana ripeness chart, and previous exposure of the banana bunch to direct or indirect sunlight, which influences the chlorophyll content and, hence, the relative greenness of unripe bananas. ARS personnel involved with the research reported herein were trained by members of the Hawaii banana industry to judge banana ripeness based on visual observation of color.

Test Insects. Adult Mediterranean and oriental fruit flies were reared (Vargas 1989) at the ARS fruit fly mass-rearing facility, Honolulu, and shipped as pupae to the ARS laboratory, Hilo. Adults emerging from the puparia were fed sugar water and protein hydrolysate for $\geq$10 d before they were used in tests. The fecundity of adult fruit flies and the viability of the eggs they produced were monitored for each banana infestation test to ensure that the results of the tests were not affected by infertility or poor egg viability.

Fecundity was verified by taking a sample of adult flies equal to the number used in the banana infestation test and placing them in a 0.3-m^3 screened cage that contained a ripe papaya, *Carica papaya* L. After the same exposure period used in the banana infestation test, the adult flies were removed and the papaya was held on larval rearing diet to recover survivors (Armstrong et al. 1984, 1995b). Banana

Table 1. Types of faults associated with culled Brazilian and Cavendish bananas in Hawaii

Fault[a]	Description and cause
Abrasions	Damage to the banana skin caused by fingers rubbing together or against another object; usually in the form of callused scars
Ant burns	Small (0.1–0.2 mm diameter) black depressions on the surface of the banana skin caused by drops of corrosive fluid regurgitated when ants, *Anoplolepis longipes* (Jerdon) (Hymenoptera: Formicidae), that congregate in banana bunches are disturbed
Cracks, splits	Openings of the skin or along the longitudinal sutures of the skin from improper irrigation or handling practices
Fused fingers	Result of incomplete separation during the early stages of growth of two or more fingers on a hand whereby the fingers are fused together longitudinally (the pulp of each banana remains separate)
Insect scars	Damage to the banana skin caused by the feeding of arthropods, such as mites, scale insects, and thrips, usually in the form of callused scars
Mechanical and miscellaneous damage	Includes punctures, bruises, cuts, and crushed fingers, which are usually the result of improper handling practices during plantation management, harvest, culling, and packing; and damage caused by feeding birds or rats
Point bruises	Darkened areas on the banana skin caused when the tip of one finger is forced against another; generally occurs during harvesting and packing operations
Precocious ripening	When one or more fingers on a green banana bunch ripen before the scheduled harvest date
Stem bend	Caused by aberrant growing patterns or improper handling practices that result in deformed curvature of the stem attaching the finger to the crown and may include splitting of the longitudinal sutures of the skin along the stem
Sun and chemical burns	Blackened areas of the banana skin caused by exposure for prolonged periods to direct sunlight or from contact with pesticides and surfactants
Tip rot and general decay	Decay caused by various plant pathogens that occurs before harvest and either is specific to the tip (blossom end) of bananas, or occurs over generalized areas of the fruit
Point scars	Scarred areas on the banana skin caused when the tip of one finger grows against another; occurs before harvest
Windburn	A form of abrasion caused when severe winds blow dust or sand particles against the banana skin

[a] All of these types of damage are common to most geographical areas where bananas are grown.

infestation test results were discarded if <50 fruit flies were recovered from the papaya.

Egg viability was verified by collecting three samples of eggs laid over a 1-h period (Armstrong et al. 1995a). Each sample of 100 eggs was placed on moist blotter paper in a covered petri dish and held at ambient temperature (24 ± 3°C) for ≈1 wk to determine percentage eclosion. If the percentage of eclosion in any of the three petri dishes was <60%, the banana infestation test corresponding with the egg viability test was discarded.

Test Fruit. All Brazilian (henceforth, "Brazilian" refers to dwarf Brazilian unless otherwise noted), Grand Nain, Valery, and Williams bananas were from commercial plantations. Banana bunches brought to the laboratory were at the green stage of harvest maturity. Harvest maturity was determined by individual growers according to a set time interval beginning when the blossom is removed from the terminus and the bunch is covered with an opaque polyethylene bag to prevent sunburn. All bananas were examined for the presence of fruit flies and other insects before they were used in tests.

Washing banana hands (group of bananas, or fingers, attached to the stalk by a common stem section called a "crown") and clusters (smaller groups of bananas separated from hands remaining joined by sections of crown) in chlorine-water solution to clean the fruit and staunch the latex exudate after they are cut from the bunch is a standard industry practice. However, harvested bananas brought to the laboratory for infestation tests were not washed to retain the fruit surfaces in the same condition as those presented to fruit flies for oviposition in the plantation. Additionally, the washing process could remove insects from the fruit surfaces.

Culled Banana Samples. "Culled" bananas refers to aberrant or damaged fruit that are discarded when harvested bunches are separated into hands and clusters (hands separated into smaller groups) at the packing house. The different fruit aberrations or types of damage associated with culled bananas (Table 1) that could be susceptible to fruit fly oviposition and infestation are hereafter referred to as "faults" (Miller and Chang 1998). The same faults are found in all cultivars of banana in Hawaii, and they are common to most geographical areas where bananas are grown.

Samples of culled bananas were collected from cull dumps at packing houses on the islands of Hawaii, Kauai, Molokai, Maui, and Oahu to determine whether different faults pose a quarantine security risk if exported. The collection of culled dwarf Brazilian bananas was emphasized over the collection of culled Cavendish bananas because the dwarf Brazilian had not been studied previously (Armstrong 1983). On the island of Hawaii, culled banana samples were collected weekly for 1 yr from six packing houses representing fruit harvested from five different plantations in the Puna District from lower Keaau to Mountain View. On Oahu, culled banana samples were collected six times at 4- to 6-wk intervals from each of three banana packing houses located on plantations in Waimanalo, Kahaluu (Koolaupoko District), and Kahuku (Koolauloa District). On Kauai (Kapaa in Kawaihau District), Molokai (Molokai Agricultural Park in Hoolehua District), and Maui (Pulehu in Makawao District), three to six culled banana samples were collected at 6- to 8-wk intervals from one packing house on each island. Culled bananas from Kauai, Molokai, and Maui were collected to provide supplementary data because banana production on these islands is limited compared with Hawaii and Oahu. Culled banana samples from Kauai, Molokai, Maui, and Oahu were packed in sealed fiberboard cartons at the time of collection and shipped by air to Hilo.

Perforated, zip-seal, polyethylene bags (24.5 cm by 15.0 cm; 0.95-liter capacity) were used to hold bananas in the laboratory. The perforations (a total of ≈650, 0.1-mm-diameter holes in each bag), which prevented the accumulation of excess moisture, were made with a No. 113-535 Wartenberg medical pin wheel (Tisco Surgical Instruments, Hicksville, NY) before the bags were used. Each bag was placed flat on a wooden board and the medical pinwheel was rolled over the surface of the bag in parallel lines ≈2 cm apart so that the tines perforated both sides of the bag. Culled banana samples were brought to the laboratory, separated into individual fingers with a knife, and examined for insects other than fruit flies. The fingers were separated by the type of fault, numbered with a felt-tip marking pen, weighed, and held individually in the perforated polyethylene bags. After a culled banana was placed in each bag, dry fruit fly larval diet (≈50 ml per bag) was added to provide optimum conditions for fruit fly survival (Armstrong et al. 1984), and the bag was sealed. Each bag containing a banana and larval diet was held at ambient temperature (25 ± 5°C) until the fruit had deteriorated (≈2 wk). Fluids from the deteriorating fruit moistened the larval diet to provide a medium in which larvae could continue their development to the pupal and adult stages after leaving the fruit (Armstrong et al. 1984). After the 2-wk holding period, the bags with fruit fly larval diet and banana debris were opened and the contents were thoroughly examined for fruit fly larvae, pupae, and adults, and for insects other than fruit flies.

Fruit Fly Trapping Surveys. Concurrent with the culled banana samples, trapping surveys were done on the island of Hawaii, Puna District (presently the largest banana-growing area in the state), to detect the presence of Mediterranean fruit fly, melon fly, and oriental fruit fly in four plantations and five packing houses that serviced these plantations from which culled banana samples originated. The trapping surveys were done with McPhail traps containing protein bait or Jackson traps containing cuelure, methyl eugenol, or trimedlure (Cunningham 1989). The protein-baited McPhail traps were used in packing houses because their relatively short-range attractancy would not increase fruit fly populations in the fruit handling areas by attracting adult flies from long distances. Conversely, Jackson traps, which have a greater range of attractancy, were used in each banana plantation to attract fruit flies from longer distances within the plantation.

One McPhail trap was placed in close proximity to the cull dump at each packing house. The traps were suspended by string from the ceiling or roof so the trap was 2.0–2.7 m from the floor. The McPhail traps were left in the packing houses for the duration of the culled banana sample collection period and serviced (Cunningham 1989) once every 2 wk. Fruit flies caught in the McPhail traps were brought to the laboratory for identification.

Jackson traps baited with cuelure, methyl eugenol, or trimedlure were placed in each plantation to trap melon fly, oriental fruit fly, or Mediterranean fruit fly, respectively. A trap site consisted of three Jackson traps, one trap for each of the three male lures. Each Jackson trap at a trap site was suspended by string from banana leaf stem so the trap was 1.5–2.0 m from the ground. One trap site each was placed at the approximate centers of a 4.0-ha plantation and a 6.0-ha plantation, four trap sites were placed in a 34.4-ha plantation, and 12 trap sites were placed in a 113.3-ha plantation. The single trap sites at the centers of the 4.0- or 6.0-ha plantations were ≈41 m or ≈73 m from the nearest periphery, respectively. The multiple trap sites in the two larger plantations were placed ≈30 m apart along an imaginary line through the center of the widest area of each plantation. The first and last trap sites were ≈10 m inside the plantation. For the duration of the culled banana sample collection, Jackson traps were placed in the plantations once every 2 wk for a 4-h period. Short trapping periods were used to show the presence of fruit flies in the plantations without increasing fruit fly populations by attracting flies from outside areas. After the 4-h trapping period, the Jackson traps were removed to the laboratory, and trapped fruit flies were identified and counted.

Plantation Infestation Tests. Only Brazilian bananas were used in plantation infestation tests. APHIS-PPQ was specifically concerned with the infestability of these bananas on account of their ripening characteristics. Although test procedures were similar to those recommended by Cowley et al. (1992) for determining fruit fly host status for fresh fruits, the number (1,000) of gravid females to which bananas (≈100) were exposed in a portion of the tests was double the recommended number in an attempt to force infestation to occur.

Green Bunches. Infestation tests were done in a plantation to determine whether Mediterranean or oriental fruit fly would oviposit into green bananas in a bunch attached to the plant. A banana bunch (≈100 fingers) attached to the plant was enclosed in a 1.25-m^3 cage described by Armstrong (1983) and exposed to 1,000 gravid female Mediterranean or oriental fruit flies for 24 h. After the 24-h exposure period, the caged bunch was harvested and brought to the laboratory. The bunch was removed from the cage and separated into hands. As the bunch was separated, all female fruit flies were removed and the bananas were examined for the presence of insects other than fruit flies. The number of ovipositor wounds was recorded, and fingers with no ovipositor wounds were discarded. Initially, all hands were separated into fingers, and the fingers were held individually in 0.95-liter, perforated polyethylene bags with the same conditions as described for culled banana samples to observe for fruit fly survival. After repeating the plantation infestation test twice for Mediterranean fruit fly and three times for oriental fruit fly, the holding conditions were changed to simulate the actual conditions for packing bananas, and the infestation tests were repeated with 500 or 1,000 female Mediterranean or oriental fruit flies. Bananas are packed in cartons as clusters; individual fingers are not packed. Therefore, instead of separating the hands into fingers, the hands were separated into clusters of more than five bananas and held in 3.79- or 7.57-liter bags, depending on the size of the cluster. The 3.79-liter bags were identical to those described above for the laboratory infestation tests. The 7.57-liter bags (39.5 cm high by 30.5 cm wide) had ≈3,000 perforations in the surface and contained ≈150 ml of fruit fly larval rearing diet. All other holding conditions were the same as those described for culled banana samples. The plantation infestation tests with bananas held as clusters to observe for fruit fly survival were repeated four times each for Mediterranean and oriental fruit fly.

Green Bunches 1 Week Past Scheduled Harvest Date. Standard industry practice in Hawaii is to attach color-coded tags or ribbons that identify the harvest dates of banana bunches so that all bunches of a certain age will be harvested at the same time, although a bunch scheduled for harvest on a specific date may be overlooked for a week or longer. A bunch (≈100 fingers) of green bananas was left attached to the plant for 1 wk beyond the scheduled harvest date, and then enclosed in a 1.25-m^3 cage as described above. The caged bunch was exposed to 1,000 gravid female Mediterranean or oriental fruit flies for 24 h. After the 24-h exposure period, the caged bunch was harvested and brought to the laboratory. After the bunch was removed from the cage and fruit flies were discarded, the bananas were examined for insects other than fruit flies. The hands were separated into clusters of four to six fingers, the number of ovipositor wounds was recorded, and the clusters were held in 3.79- or 7.57-liter bags to observe fruit fly survival as described above. Three repetitions of the infestation tests were done for each fruit fly species.

Green Bunches That Included Precociously Ripened Fingers. A bunch (≈100 fingers) of green bananas attached to a plant that had one or more precociously ripened fingers was enclosed in a 1.25-m^3 cage as described above. The caged bunch was exposed to 1,000 gravid female oriental fruit flies (three repetitions) or 250, 500, or 1,000 gravid female Mediterranean fruit flies (three repetitions of each level of infestation severity) for 24 h. After the 24-h exposure period, the caged bunch was harvested and examined as for green bunches past their scheduled harvest date.

Harvested Green Bunches Exposed to Natural Mediterranean Fruit Fly Populations. Tests were done to determine the infestability of green bananas by natural fruit fly populations. A bunch of bananas was harvested from a banana plantation in Hawaii County, Holualoa, Kona District, and placed in an adjacent coffee, *Coffea arabica* L., plantation for a 24-h exposure period. A length of rope was tied around the stalk near the cut end and the bunch was suspended from a stepladder so that the terminus of the bunch was ≈1 m from the ground. A hand of bananas harvested ≈1.5 wk earlier and held in the laboratory until ripe was similarly suspended ≈10 m from the bunch. The bananas were surrounded and partially shaded by coffee plant foliage. After the 24-h exposure period, the bananas were brought to the laboratory. The bunch was separated into hands and the number of ovipositor wounds on the unripe and ripe fingers was recorded. The hands were held in 7.57-liter bags to observe for fruit fly survival as described above for plantation infestation tests with green bunches. The infestation test was repeated five times over a 2-wk period. The presence of Mediterranean fruit fly during the infestation tests was confirmed by monitoring with Jackson traps containing trimedlure (Cunningham 1989). Two Jackson traps were placed in the coffee plantation 1 wk before the tests were initiated and maintained within ≈50 m of the suspended bananas for the duration of the test. The Jackson traps were serviced twice each week and the number of trapped Mediterranean fruit flies was recorded.

The same test was repeated five times over a 3-wk period on the island of Kauai, Koloa District. A green banana bunch was harvested from a plantation located in Koloa and transported (≈30 min) to a coffee plantation located in Numila. The green bunch and a hand of ripe bananas were suspended in coffee foliage, exposed, and examined as described above. The presence of Mediterranean fruit fly during the infestation tests was confirmed by monitoring with Jackson traps containing trimedlure (Cunningham 1989). Three Jackson traps were placed in the coffee plantation for 5-d intervals beginning 1 wk before the infestation tests were initiated and maintained for the duration of the tests within ≈100 m of the suspended bananas. The Jackson traps were serviced at 5-d intervals, when the traps were removed from the plantation for 2 d and the number of trapped Mediterranean fruit flies was recorded.

Laboratory Infestation Tests. Infestation tests were done in the laboratory to determine what factors influenced Mediterranean or oriental fruit fly oviposition and survival in green Brazilian bananas, including the number of gravid females present (infestation pressure), the elapsed time after harvest, and whether individual fingers were more at risk of infestation than bananas in clusters. Bananas used in all laboratory infestation tests were examined for the presence of insects before use.

Banana bunches were harvested from local plantations and brought directly to the laboratory where they were separated into clusters of five fingers each.

Six clusters each were used immediately for infestation tests, or held for use in infestation tests at 1, 2, or 3 d after harvest.

Individual clusters (0, 1, 2, or 3 d after harvest) were placed in six 0.3-m^3 screen cages and exposed to infestation by five (two cages each containing 25 gravid females), 15 (two cages each containing 75 gravid females), or 25 (two cages each containing 125 gravid females) female Mediterranean or oriental fruit flies per banana finger for 3 h. The three infestation pressures were not intended to simulate actual field conditions but were chosen arbitrarily to evaluate whether increasing infestation pressure would contribute to the risk of infestation. After the 3-h exposure period, the clusters were removed and the number of ovipositor wounds (puncture wounds made by ovipositor insertion) on each finger was counted. One cluster each that had been exposed to 5, 15, or 25 female fruit flies per finger at 0, 1, 2, or 3 d after harvest was divided into fingers. The fingers were held individually in 0.95-liter perforated, polyethylene bags under the same conditions as described above for culled banana samples to observe for fruit fly survival. All ovipositor wounds on the remaining clusters were excised from the banana skin with a scalpel, forceps, and dissecting microscope, and the number of eggs present in each wound was counted.

To observe for potential differences in risk of infestation between single fingers and clusters, another infestation test was done identically except that bananas held to observe for fruit fly survival were not separated into fingers. One cluster each that had been exposed to 5, 15, or 25 female fruit flies per finger at 0, 1, 2, or 3 d after harvest was placed in a perforated, zip-seal, polyethylene bags (3.79-liter capacity). All holding conditions were the same except that ≈100 ml of dry fruit fly larval rearing diet was added to each bag. Each laboratory infestation test was repeated three to five times for each fruit fly species.

Banana Color, Firmness, Recency of Harvest, and Infestability Correlation Tests. Color and firmness are two physical attributes of fruit that are frequently related to harvest maturity. Couey and Hayes (1986) used *L-a-b* color measurements of reflected light from papaya surfaces to provide a fruit maturity standard that was correlated to risk of fruit fly infestation, and measurement of fruit firmness is used commercially to evaluate tomato ripeness (Kader et al. 1978). Surface *L-a-b* color and fruit firmness measurements of green Brazilian bananas were made to determine whether simple analytical methods could replace subjective visual inspection by defining a "greenness" standard that was directly related to recency of harvest and risk of Mediterranean or oriental fruit fly infestation.

Color and Firmness Measurements and Recency of Harvest. Banana bunches were harvested from local plantations, brought to the laboratory, and examined for the presence of insects. The bunches were held at ambient temperature (24 ± 3°C), and fingers were removed from the bunches immediately (0 d) or at 1, 2, or 3 d after harvest. Four circles (≈4 cm in diameter) were drawn with a felt-tip pen along an imaginary line on one side of each finger between the stem- and the blossom-ends. The distance between each circle and between the stem- and blossom-ends and the nearest circles was approximately equal. The banana skin color inside each of the four circles was measured with a colorimeter (Chroma Meter CR200 Color Analyzer, Minolta, Ramsey, NJ) calibrated before each test with the standard white plate provided with the colorimeter kit. The colorimeter measured the colors reflected from the banana surface in the *L-a-b* ranges from black to white (*L*), from red to green (*a*), and from yellow to blue (*b*). Each time the colorimeter head was pressed against the fruit surface, three measurements of the reflected light were made, averaged, and recorded.

Firmness, a measurement of the force required to puncture the skin, was measured at the approximate center of each of the four circles with a penetrometer (Ametek 100 Motorized Test Stand fitted with an Accuforce Cadet 0–50 kg Force Gauge, Mansfield and Green Division, Largo, FL). The penetrometer applied pressure to the banana surface until the blunt, 8-mm-diameter tip of the force gauge punctured the skin. *L-a-b* surface color and firmness was measured as described for 470 banana fingers.

Color Measurements and Infestability. To determine whether risk of Mediterranean or oriental fruit fly infestation could be correlated to *L-a-b* color measurements, the surface color was measured for bananas used for the previously described infestation tests in the laboratory. *L-a-b* color measurements were made on the side of each banana as previously described, except that only one averaged measurement was made at the approximate center on the side of each banana. No attempt to was made to test for correlations between banana firmness and infestability because of the damage to the skin caused by the penetrometer.

Data Analysis. Data from the infestation tests in the laboratory, the *L-a-b* color measurements, and the banana firmness measurements were analyzed with Statistical Analysis Systems version 6.12 (SAS Institute 1990). Mean differences were analyzed with the general linear models (PROC GLM) procedure, and significant differences in treatment means were determined with Student–Newman–Keuls test at the $P = 0.05$ level. Correlation analyses were done with the Spearman's rank-order.

Results and Discussion

Culled Banana Samples. Although >3.5 times more culled Brazilian bananas than culled Cavendish bananas were collected, the same types of faults were found in all cultivars (Table 2). Only oriental fruit flies were reared from the culled banana samples (Table 2), which concurs with Armstrong (1983), although both melon fly and oriental fruit fly populations were present at two cull dumps on the island of Oahu (Honolulu County, Kaneohe and Waimanalo districts). A characteristic of all faults (except for deformed bananas) that had oriental fruit fly infestations

Table 2. Numbers of culled dwarf Brazilian and Cavendish bananas sampled from packing houses in Hawaii with specific faults, and numbers of fruit flies and *Opogona sacchari* (Bojer) recovered

Fault	Dwarf Brazilian bananas					Cavendish[a] bananas				
	No. with fault	Oriental fruit fly infestation[b]		*O. sacchari* infestation		No. with fault	Oriental fruit fly infestation[b]		*O. sacchari* infestation	
		% infested	No. recovered	% infested	No. recovered		% infested	No. recovered	% infested	No. recovered
Cut	634	1.10	259	3.15	29	301	0.00	0	1.33	5
Split	123	0.81	29	5.69	5	172	1.74	21	2.33	10
Crushed	192	2.08	60	2.60	5	187	2.14	44	1.07	6
Abrasion	1,346	0.52	9	3.42	123	651	0.92	27	4.15	33
Precocious-ripe	247	21.46	1,416	2.83	11	40	10.00	98	0.00	0
Point bruise/scar	1,326	0.23	22	3.47	61	371	0.81	29	4.31	18
Tip rot	836	0.00	0	1.44	10	122	0.00	0	1.64	2
Thrips scar	808	0.00	0	2.47	21	145	0.00	0	6.21	11
Ant burn	490	0.41	5	3.26	18	15	0.00	0	0.00	0
Surface insects[c]	337	0.00	0	0.89	5	9	0.00	0	11.11	3
Chemical burn	49	0.00	0	8.16	7	33	0.00	0	3.03	1
Sunburn	139	0.00	0	1.44	3	53	0.00	0	0.00	0
Stem bend[d]	412	1.94	78	3.40	24	81	0.00	0	7.41	9
Puncture[d]	650	0.15	157	2.46	27	190	0.53	1	3.16	14
Puncture[e]	537	0.00	0	2.61	15	133	0.00	0	3.01	7
Crack[d]	258	2.33	31	0.77	20	51	0.00	0	0.00	0
Crack[e]	59	0.00	0	1.69	2	11	0.00	0	0.00	0
Windburn	5	0.00	0	0.00	0	0	0.00	0	0.00	0
Bird peck	1	0.00	0	0.00	0	3	0.00	0	0.00	0
Fused fingers[f]	500	0.02	39	1.00	12	67	1.49	21	2.98	2
Decay (general)	329	0.00	0	1.52	10	28	0.00	0	0.00	0
Total	9,278	1.00	2,105	2.65	408	2,663	0.83	241	7.89	121

[a] Cavendish bananas included Valery, Williams, and Grand Nain.
[b] Oriental fruit fly only; no Mediterranean fruit fly or melon fly were recovered from bananas with faults.
[c] Surface insects directly affecting whether bananas were culled included coconut scale, green scale, and *Pseudococcus elisae.* Thrips, aphids, and other surface feeders were not included.
[d] Fruit flesh was exposed by bend causing splitting of skin, puncture through skin into fruit flesh, or crack exposing fruit flesh.
[e] Puncture or crack did not penetrate completely through skin to expose fruit flesh.
[f] Two or more banana fingers fused together.

was penetration of the skin to the fruit flesh. Bananas with punctures or cracks that did not penetrate the skin to the fruit flesh were not infested (Table 2). The lack of melon fly infestation, even in precociously ripened culled bananas (Table 2), further demonstrates the nonhost status of banana for this fruit fly species.

Adult *Opogona sacchari* (Bojer) (Lepidoptera: Tineidae) was also reared from both culled Brazilian and Cavendish bananas (Table 2). *O. sacchari* is known from tropical to subtropical humid regions around the world (Davis and Peña 1990). *O. sacchari* first became established in Hawaii circa 1989 (Davis and Peña 1990), and is not considered by growers to be a pest in either producing or marketing bananas within the state. The general consensus among growers during the late 1990s was that *O. sacchari* infestations were limited primarily to the banana growing areas in the Puna District of Hawaii County. Culling at the packing house was adequate to maintain bananas packed for market free of *O. sacchari* during the inspections of packed fruit made by APHIS-PPQ concurrent with the culled banana sample study (Miller and Chang 1998).

Other insects of potential quarantine importance were occasionally observed from both Brazilian and Cavendish banana bunches harvested for tests (Table 2). The insects other than oriental fruit fly or *O. sacchari* found on bananas included coconut scale, *Aspidiotus destructor* Signoret (Homoptera: Diaspididae); green scale, *Coccus viridis* (Green) (Homoptera: Coccidae); *Pseudococcus elisae* Borchsenius (Homoptera: Pseudococcidae); and several species of ants (Hymenoptera: Formicidae), aphids (Homoptera: Aphididae), earwigs (Dermaptera: Chelisochidae and Forficulidae), thrips (Thysanoptera: Thripidae), and cockroaches (Orthoptera: Blattidae). Coconut scale is quarantined by California, green scale is a federal quarantine pest, and the other insects, although not regulated as quarantine pests (so-called "hitchhikers"), may or may not cause problems for bananas entering California or other areas (e.g., Guam). Although these insects were observed infrequently, a single live insect of quarantine importance found in exported bananas may cause regulatory action (Miller and Chang 1998). Furthermore, live insects of quarantine importance and hitchhikers may cause unacceptable delays at ports-of-entry while insect species are identified and their regulatory status is determined. Standard banana packing practices, especially washing the hands in chlorine-water solution after they are cut from the bunch, could be expected to remove most mobile insects. However, sessile insects, such as scales and mealybugs, may require the application of control measures before harvest, including insecticide application in the plantation, integrated pest management strategies, or changes in cultural practices.

Table 3. Results of infestation tests in plantations with green dwarf Brazilian banana bunches at scheduled harvest date, at 1 wk past scheduled date, or with some precociously ripened fingers caged on the plant and exposed to gravid Mediterranean or oriental fruit fly females for 24 h, and then harvested and held in the laboratory to recover fruit flies

Fruit fly species	Total no.					
	Gravid females	Bananas on bunch[a]	Discarded fingers[a]	Bananas held for observation[a]	Oviposition wounds[a]	Fruit flies recovered
	Bunches caged at harvest date[b] (separated into fingers[c])					
Mediterranean fruit fly ($n = 2$)	1,000	98.5 ± 4.5	0	98.5 ± 4.5	668.5 ± 238.5	19
Oriental fruit fly ($n = 3$)	1,000	96.7 ± 8.2	0	96.7 ± 8.2	95.7 ± 8.2	0
	Bunches caged at harvest date[b] (separated into clusters[c])					
Mediterranean fruit fly ($n = 3$)	500	149.0 ± 10.5	0	149.0 ± 10.5	523.3 ± 78.9	0
	1,000	98.8 ± 14.2	0	98.8 ± 14.2	857.0 ± 165.1	2
Oriental fruit fly ($n = 3$)	500	121.7 ± 17.7	0	121.7 ± 17.7	51.3 ± 8.4	0
	1,000	122.8 ± 11.8	0	122.8 ± 11.8	85.6 ± 24.8	0
	Bunches caged one wk past harvest date[b] (separated into clusters[c])					
Mediterranean fruit fly ($n = 3$)	1,000	147.0 ± 5.0	0	147.0 ± 5.0	978.7 ± 270.3	0
Oriental fruit fly ($n = 3$)	1,000	144.7 ± 5.2	0	144.7 ± 5.2	55.7 ± 16.1	0
	Bunches with precociously ripened fingers caged at harvest[b] (separated into clusters[c])					
Mediterranean fruit fly ($n = 3$)	250	139.3 ± 12.7	31.0 ± 8.9[d]	69.7 ± 23.6	439.7 ± 195.4	2
	500	115.0 ± 12.7	28.0 ± 3.2[d]	84.3 ± 4.9	647.3 ± 89.2	3
	1,000	113.0 ± 24.7	31.3 ± 6.8[d]	81.3 ± 30.9	2,049.3 ± 423.5	36
Oriental fruit fly ($n = 3$)	1,000	75.0 ± 15.6	15.0 ± 7.0[d]	81.3 ± 30.9	168.3 ± 135.4	0

[a] Mean ± SE.
[b] Bunches were caged within 24 h of scheduled harvest date, or within 24 h of the date 1 wk past the scheduled harvest date.
[c] Bunches were separated into individual fingers or in clusters of five or more fingers and held in the laboratory to recover fruit flies.
[d] Precociously ripened fingers and fingers without oviposition wounds were discarded (oviposition wounds were not recorded from precociously ripened fingers).

Fruit Fly Trapping Surveys. No Mediterranean fruit flies were captured, which concurs with Liquido et al. (1989), who showed that Mediterranean fruit fly seldom occur in the areas of the Puna District where banana, papaya, and other tropical fruits are grown.

The number of melon flies caught was 0.63 ± 0.26 ($n = 8$), 0 ($n = 9$), 2.36 ± 0.39 ($n = 73$), and 1.52 ± 0.42 ($n = 44$) in traps located in the four plantations, and 0 ($n = 19$), 0.06 ± 0.06 ($n = 18$), 0.67 ± 0.37 ($n = 18$), 0.11 ± 0.08 ($n = 18$), and 1.83 ± 0.41 ($n = 36$) in the packing houses. The number of oriental fruit flies caught in traps was 46.25 ± 7.97 ($n = 8$), 45.00 ± 7.13 ($n = 9$), 81.60 ± 8.75 ($n = 73$), and 57.43 ± 7.09 ($n = 44$) in the four plantations, and 2.74 ± 1.09 ($n = 19$), 28.17 ± 5.99 ($n = 18$), 2.17 ± 1.02 ($n = 18$), 7.06 ± 5.23 ($n = 18$), and 23.64 ± 5.61 ($n = 36$) in the packing houses. The relatively low number of melon flies trapped compared with the number of oriental fruit flies trapped in both the plantations and packing houses concurs with Liquido et al. (1989), who demonstrated that oriental fruit fly was the more prevalent of the two fruit fly species found in the areas of the Puna District where banana, papaya, and other tropical fruits are grown.

Plantation Infestation Tests. *Green Bunches at Scheduled Harvest Date.* Mediterranean fruit flies (19 total) were recovered from bananas in one of two test repetitions in which the bunches were separated into fingers (Table 3) before the test methods were modified to simulate standard banana packing procedures by separating the bunches into clusters. In test repetitions where the banana bunches were separated into clusters after exposure to infestation, 0–2 Mediterranean fruit flies were recovered from bunches exposed to 500 or 1,000 gravid females, respectively (Table 3). No recovery of Mediterranean fruit fly from banana bunches exposed to 500 gravid females demonstrates nonhost status consistent with the recommendations of Cowley et al. (1992). The results also show that Mediterranean fruit fly infestations can be forced at an infestation pressure of 1,000 gravid females, regardless of whether the bunch was separated into fingers or clusters (Table 3). Recovery of Mediterranean fruit flies from banana bunches exposed to 1,000 gravid females (Table 3) does not necessarily indicate host status because the infestations may be artifacts of the severe infestation pressure and artificial environment in which no preferred host was available (Armstrong 1994). However, the results (Table 3) provide a regulatory parameter for green Brazilian banana host status: Mediterranean fruit fly fruit fly infestations in plantations cannot exceed 500 gravid females per bunch.

Table 4. Results (mean ± SE) of infestation tests with green bunches and ripe clusters of dwarf Brazilian bananas exposed to natural Mediterranean and oriental fruit fly populations in coffee plantations

No. green bananas[a]					No. ripe bananas[a]			
Fingers on bunches	Fingers with oviposition wounds	Oviposition wounds	Mediterranean fruit flies recovered	Oriental fruit flies recovered	Bananas in clusters	Oviposition wounds	Mediterranean fruit flies recovered	Oriental fruit flies recovered
Holualoa coffee plantation[b]								
98.8 ± 9.3	2.0 ± 1.3	2.4 ± 1.4	0	0	5.4 ± 0.6	9.2 ± 7.0	0	4.2 ± 3.5
Numila coffee plantation[b]								
91.0 ± 8.5	14.0 ± 9.3	45.2 ± 38.0	0	0	6.0 ± 0.8	37.0 ± 11.7	4.2 ± 1.4	2.6 ± 1.2

[a] Exposed for 24 h to Mediterranean fruit fly populations in coffee plantations located in Holualoa, island of Hawaii ($n = 5$) and in Numila, island of Kauai ($n = 5$).

[b] The total number of Mediterranean fruit flies trapped in coffee plantations during the infestation tests were 312 from two Jackson traps at Holualoa and 12,607 from three Jackson traps at Numila.

No oriental fruit flies were recovered from bunches that were either exposed to 1,000 gravid females and separated into individual fingers (Table 3), or exposed to 500 or 1,000 gravid females and separated into clusters. The results (Tables 3) indicate that green Brazilian bananas are not a host for oriental fruit fly, even under severe infestation pressures and conditions that do not occur in the plantation.

Green Bunches 1 Week Past Scheduled Harvest Date. No Mediterranean or oriental fruit flies were recovered from the bananas, although the bunches were left attached to the plant 1 wk past the scheduled harvest date (Table 3).

It is noteworthy that no Mediterranean fruit flies were recovered from banana bunches left in the plantation 1 wk past the scheduled harvest date (Table 3), although the infestation pressure (1,000 gravid females) was the same as that used for banana bunches exposed to infestation at the scheduled harvest date (Table 3). The lack of infestation (Table 3) indicates that the Mediterranean fruit flies recovered from the banana bunches at harvest date that were exposed to 1,000 gravid females resulted from the artificial test conditions and are not indicative of host status under commercial growing conditions.

Green Bunches That Included Precociously Ripened Fingers. Mediterranean fruit flies were recovered from green bananas on bunches that included some precociously ripened fingers whether the infestation pressure was 250 (two recovered), 500 (three recovered), or 1,000 (36 recovered) gravid females (Table 3). The low recovery rate (Table 3) compared with the severity of the infestation pressures further indicate that green Brazilian bananas are not a host for Mediterranean fruit fly. However, the recovery of Mediterranean fruit flies (Table 3) from all three tests where the infestation pressure was 1,000 gravid females and from one test repetition each when the infestation pressure was 250 or 500 gravid females indicates that green bunches that include precociously ripened fingers are at risk from infestation. Therefore, bunches of green Brazilian bananas with some precociously ripened fingers must be excluded when harvesting bananas for export.

No oriental fruit flies were recovered from the bunches of green bananas that included some precociously ripened fingers (Table 3), which further indicates that green Brazilian bananas are not a host for this fruit fly species.

Harvested Green Bunches Exposed to Natural Mediterranean Fruit Fly Populations. The mean (± SE number of Mediterranean fruit flies caught in the Jackson traps in the Holualoa, HI, coffee plantation was 57.5 ± 19.8 and 27.5 ± 17.8 for the first and second week, respectively. The mean number of Mediterranean fruit flies caught in the Jackson traps placed in the Numila, Kauai, coffee plantation was 2,188.3 ± 52.8, 1,925.7 ± 237.6, and 2,276.7 ± 147.6 for the first, second, and third week, respectively. The success of the Jackson traps in catching Mediterranean fruit flies in the two plantations demonstrated that natural populations were present during the infestation tests. The greater numbers of Mediterranean fruit flies caught in the Numila plantation compared with Holualoa plantation is indicative of the greater plantation size and amount of available host material (coffee cherries) in the Numila plantation. The presence of natural populations of oriental fruit fly in both the Holualoa and Numila plantations was demonstrated by the recovery of oriental fruit flies from the ripe bananas used in the tests (Table 4).

No Mediterranean fruit flies were recovered from the green Brazilian banana bunches (Table 4), indicating that green Brazilian bananas are not a host for this fruit fly species. No Mediterranean fruit flies were recovered from the ripe clusters of Brazilian bananas exposed to Mediterranean fruit flies in the Holualoa plantation, whereas four of the five ripe clusters used in the tests at the Numila plantation became infested, resulting in the recovery of 21 Mediterranean fruit flies (Table 4). No inference can be made regarding the greater numbers of Mediterranean fruit flies in the Numila plantation, the ≈19-fold more ovipositor wounds in the green bananas, or the approximately fourfold more ovipositor wounds in the ripe bananas than occurred in the Holualoa plantation (Table 4) because no distinction could be made between Mediterranean or oriental fruit fly ovipositor wounds. Regardless, natural populations of Mediterranean fruit fly did not produce viable infestations in green Brazilian bananas placed in either the Holualoa or Numila coffee plantations (Table 4). Although oriental fruit

Table 5. Numbers of oviposition wounds observed and eggs recovered from green dwarf Brazilian banana clusters exposed at 0, 1, 2, or 3 d after harvest to 5, 15, or 25 gravid Mediterranean or oriental fruit fly females per finger

Days after harvest	No. flies per finger	Mediterranean fruit fly[a]		Oriental fruit fly[a]	
		No. oviposition wounds[b]	No. eggs recovered[b]	No. oviposition wounds[b]	No. eggs recovered[b]
0	5	6.05 ± 0.82b	0.22 ± 0.22b	0.20 ± 0.08a	0.02 ± 0.02a
0	15	8.00 ± 1.37b	3.77 ± 1.37a	0.80 ± 0.23a	0.00a
0	25	12.66 ± 1.58a	0.51 ± 0.36b	1.69 ± 0.81a	0.11 ± 0.07a
1	5	8.00 ± 1.14b	0.70 ± 0.35a	0.57 ± 0.12a	0.10 ± 0.07a
1	15	8.23 ± 1.08b	7.47 ± 6.35a	0.73 ± 0.26a	0.00a
1	25	13.45 ± 1.45a	4.54 ± 1.87a	1.02 ± 0.23a	0.00a
2	5	6.49 ± 0.85b	4.66 ± 4.01b	0.31 ± 0.09a	0.00a
2	15	11.27 ± 1.91a	5.57 ± 1.89b	0.73 ± 0.20a	0.00a
2	25	11.49 ± 1.39a	22.69 ± 9.41a	1.02 ± 0.23a	0.31 ± 0.22a
3	5	6.87 ± 1.07b	9.55 ± 2.84a	0.53 ± 0.18b	0.62 ± 0.62a
3	15	6.97 ± 1.16b	24.17 ± 9.12a	1.07 ± 0.30b	1.13 ± 1.00a
3	25	10.34 ± 1.40a	15.34 ± 8.26a	3.00 ± 0.94a	1.14 ± 0.66a

[a] Mean ± SE for three to five test repetitions with clusters of five fingers per repetition for each combination of days after harvest and level of infestation pressure (number of fruit flies per finger).
[b] Means without columns by 0, 1, 2, or 3 d after harvest followed by the same letter are not significantly different ($P > 0.05$, Student-Newman-Keuls test).

fly was recovered from the ripe bananas, no oriental fruit flies were recovered from the green Brazilian bananas (Table 4), which provides further evidence that this banana cultivar is not a host for oriental fruit fly at the green stage of harvest maturity.

Laboratory Infestation Tests. Mediterranean fruit fly females produced significantly ($F = 431.1$; df = 1, 1,044; $P < 0.01$) more oviposition wounds and deposited significantly ($F = 39.0$; df = 1, 1,044; $P = < 0.01$) more eggs per female than did oriental fruit fly females (Table 5). Time after harvest that bananas were infested did not affect number of oviposition wounds for either species (Table 6), and interactions between days after harvest and infestation pressure were not significant. However, the numbers of oviposition wounds increased significantly with increased infestation pressure (Table 6).

Number of eggs recovered increased with time after harvest for both species and as infestation pressure increased for Mediterranean fruit fly, but not for oriental fruit fly (Table 6). A significant interaction (Table 6) occurred between time after harvest and infestation pressure for the number of eggs deposited by Mediterranean fruit fly.

Mediterranean fruit fly produced more ($F = 453.9$; df = 1, 890; $P < 0.01$) oviposition wounds per female than oriental fruit fly, and there were more ($F = 8.0$; df = 1, 1,894; $P = < 0.01$) Mediterranean fruit flies per female recovered from bananas exposed to gravid Mediterranean fruit fly females than there were oriental fruit flies recovered from bananas exposed to gravid oriental fruit fly females (Table 7).

The relationships between time after harvest, infestation pressure and numbers of oviposition wounds in bananas observed in this test (Table 8) concur with the results of the previous tests for both Mediterranean and oriental fruit fly (Table 6). The numbers of Mediterranean and oriental fruit fly oviposition wounds (Tables 5 and 7) increased significantly (Tables 6 and 8) with increased infestation pressure. When the numbers of oviposition wounds for each fruit fly species (Tables 5 and 7) were divided by the number of females to remove the factor of increased infestation pressure and analyzed for differences between time after harvest, there were no significant differences for either Mediterranean ($F = 1.28$; df = 3, 890; $P = 0.28$) or oriental fruit fly ($F = 1.17$; df = 3, 1,044; $P = 0.32$). Based on the numbers of oviposition

Table 6. ANOVA tables for numbers of oviposition wounds observed and eggs recovered from green dwarf Brazilian banana clusters exposed at 0, 1, 2, or 3 d after harvest to 5, 15, or 25 gravid Mediterranean or oriental fruit fly females per finger

Source	Mediterranean fruit fly			Oriental fruit fly		
	F	df	$P > F$	F	df	$P > F$
			No. of oviposition wounds observed			
No. days after harvest	2.01	3	0.11	1.64	3	0.18
No. gravid females	21.60	2	<0.01	17.70	2	<0.01
Days × females	0.95	6	0.46	0.74	6	0.61
Error	—	493	—	—	528	—
			No. of eggs recovered			
No. days after harvest	17.70	3	<0.01	3.44	3	0.02
No. gravid females	11.10	2	<0.01	1.63	2	0.20
Days × females	2.29	6	0.03	0.91	6	0.49
Error	—	490	—	—	528	—

Table 7. Numbers of oviposition wounds observed and fruit flies recovered from green dwarf Brazilian banana clusters exposed at 0, 1, 2, or 3 d after harvest to 5, 15, or 25 gravid Mediterranean or oriental fruit fly females per finger, then separated into fingers or held as clusters after exposure to the fruit flies

Days after harvest	No. flies per finger	Mediterranean fruit fly[a]		Oriental fruit fly[a]	
		No. oviposition wounds[b]	No. flies recovered[b]	No. oviposition wounds[b]	No. flies recovered[b]
		Clusters separated into fingers after exposure to fruit flies			
0	5	8.75 ± 1.52a	0.00a	0.00a	0.00
0	15	8.27 ± 1.88a	0.40 ± 0.40a	0.67 ± 0.21a	0.00
0	25	10.20 ± 1.30a	0.00a	0.80 ± 0.31a	0.00
1	5	9.59 ± 3.00a	0.00	0.00a	0.00
1	15	7.20 ± 1.63a	0.00	1.00 ± 0.32a	0.00
1	25	11.13 ± 2.54a	0.00	0.64 ± 0.33a	0.00
2	5	7.73 ± 1.59a	0.67 ± 0.45a	0.13 ± 0.13b	0.00
2	15	8.20 ± 1.85a	0.67 ± 0.46a	0.80 ± 0.28ab	0.00
2	25	10.87 ± 1.84a	0.00a	1.20 ± 0.28a	0.00
3	5	7.70 ± 1.67a	1.10 ± 0.59a	0.00b	0.00
3	15	7.20 ± 2.39a	2.40 ± 1.43a	0.80 ± 0.34a	0.00
3	25	10.40 ± 1.90a	0.00a	0.84 ± 0.19a	0.00
		Clusters not separated after exposure to fruit flies			
0	5	4.64 ± 0.89c	0.00a	1.00 ± 0.33a	0.00
0	15	10.33 ± 1.72b	0.07 ± 0.07a	0.80 ± 0.26a	0.00
0	25	15.85 ± 2.60a	0.00a	0.85 ± 0.26a	0.00
1	5	7.12 ± 1.02a	0.00a	0.12 ± 0.07a	0.00
1	15	13.53 ± 1.46a	0.87 ± 0.87a	0.73 ± 0.40a	0.00
1	25	15.55 ± 4.84a	0.00a	1.20 ± 0.48a	0.00
2	5	8.56 ± 1.00c	0.00a	0.80 ± 0.28a	0.00
2	15	22.93 ± 3.00a	1.13 ± 0.08a	0.73 ± 0.36a	0.00
2	25	15.60 ± 1.44b	0.50 ± 0.50a	0.50 ± 0.15a	0.00
3	5	7.36 ± 0.84b	0.00a	0.46 ± 0.28a	0.00a
3	15	17.33 ± 2.10a	4.33 ± 3.74a	0.73 ± 0.28a	0.00a
3	25	14.00 ± 2.84a	0.55 ± 0.46a	2.50 ± 0.81a	0.45 ± 0.45a

[a] Mean ± SE for three to five test repetitions with clusters of five fingers per repetition for each combination of days after harvest and level of infestation pressure (number of fruit flies per finger).

[b] Means within columns by 0, 1, 2, or 3 d after harvest followed by the same letter are not significantly different ($P > 0.05$, Student-Newman-Keuls test).

wounds per female fruit fly, the suitability of Brazilian bananas as a host for either fruit fly species did not increase over the time (0, 1, 2, or 3 d) after harvest. There were no significant differences ($F = 2.07$; df = 3, 539; $P = 0.10$) between the number of eggs deposited on the basis of eggs per female for oriental fruit fly. However, there was a significant difference ($F = 10.60$; df = 3, 501; $P < 0.01$) between the numbers of eggs deposited per female for Mediterranean fruit fly, with 0 d = 1 d = 2 d < 3 d. Based on the numbers of eggs deposited, the host suitability of Brazilian bananas did not increase over time after harvest for oriental fruit fly and did not increase until 3 d after harvest for Mediterranean fruit fly.

Separating or not separating clusters into fingers after infestation had no effect on the recovery of Mediterranean or oriental fruit fly from infested Brazilian bananas (Table 8), which indicates that single green Brazilian bananas are no more at risk of Mediterranean or oriental fruit fly infestation than green

Table 8. ANOVA tables for numbers of oviposition wounds observed and fruit flies recovered from green dwarf Brazilian banana clusters exposed at 0, 1, 2, or 3 d after harvest to 5, 15, or 25 gravid Mediterranean or oriental fruit fly females per finger, then separated into fingers or held as clusters after exposure to the fruit flies

Source	Mediterranean fruit fly			Oriental fruit fly		
	F	df	$P > F$	*F*	df	$P > F$
			No. oviposition wounds observed			
No. days after harvest	2.32	3	0.08	1.44	3	0.24
No. gravid females	12.40	2	<0.01	13.00	2	<0.01
Days × females	0.87	6	0.20	1.32	6	0.25
Error	—	420	—	—	447	—
			No. fruit flies recovered			
Fingers versus clusters	1.22	1	0.27	0.91	1	0.34
No. days after harvest	5.05	3	<0.01	1.00	3	0.39
No. gravid females	6.81	2	<0.01	0.95	2	0.39
Days × females	0.77	6	0.60	0.78	6	0.59
Error	—	490	—	—	528	—

Brazilian bananas in clusters when exposed to gravid females in cages.

Banana Color, Firmness, Recency of Harvest, and Infestability Correlation Tests. *Color and Firmness Measurements and Recency of Harvest.* There were no correlations between the L ($r = -0.06$, $n = 1{,}880$, $P < 0.01$), a ($r = -0.07$, $n = 1{,}880$, $P < 0.01$), or b ($r = -0.02$, $n = 1{,}880$, $P = 0.3$) color measurements and time after harvest. Similarly, there were no correlations between the L ($r = -0.06$, $n = 1{,}880$, $P = 0.02$), a ($r = 0.07$, $n = 1{,}880$, $P < 0.01$), or b ($r = -0.02$, $n = 1{,}880$, $P = 0.51$) firmness measurements and time after harvest. The lack of correlation between either L-a-b color or firmness measurements and the time after harvest may be the result of color or firmness changes too small to measure with the equipment used in these tests. Hence, the use of more sensitive equipment for measuring color or firmness should be investigated. In the absence of analytical methods to determine banana ripeness on the basis of color, firmness, or some other characteristic, visual observation by trained industry and regulatory personnel will remain the only method for determining the ripeness of bananas exported from Hawaii or elsewhere.

Color Measurements and Infestability. There were no correlations between the L ($r = 0.01$, $n = 412$, $P = 0.01$), a ($r = 0.16$, $n = 412$, $P < 0.01$), or b ($r = -0.12$, $n = 412$, $P = 0.02$) measurements and the numbers of Mediterranean fruit fly oviposition wounds in bananas; no correlations between the L ($r = -0.01$, $n = 500$, $P = 0.89$), a ($r = 0.07$, $n = 500$, $P = 0.10$), or b ($r = -0.06$, $n = 500$, $P = 0.20$) measurements and the numbers of eggs deposited in bananas; and no correlations between the L ($r = -0.10$, $n = 415$, $P = 0.03$), a ($r = 0.08$, $n = 415$, $P = 0.10$), or b ($r = -0.10$, $n = 415$, $P = 0.03$) measurements and the numbers of Mediterranean fruit flies recovered from infested bananas. Similarly, there were no correlations between the L ($r = -0.01$, $n = 535$, $P = 0.82$), a ($r = -0.01$, $n = 535$, $P = 0.65$), or b ($r = 0.06$, $n = 535$, $P = 0.14$) measurements and the numbers of oriental fruit fly oviposition wounds; no correlations between the L ($r = -0.01$, $n = 535$, $P = 0.78$), a ($r = 0.02$, $n = 535$, $P = 0.62$), or b ($r = 0.01$, $n = 535$, $P = 0.78$) measurements and the numbers of eggs deposited in bananas; and no correlations between the L ($r = -0.10$, $n = 415$, $P = 0.03$), a ($r = 0.08$, $n = 415$, $P = 0.10$), or b ($r = -0.10$, $n = 415$, $P = 0.03$) measurements and the numbers of oriental fruit flies recovered from infested bananas. The lack of correlation between the L-a-b color measurements and numbers of oviposition wounds, eggs deposited, and Mediterranean or oriental fruit flies recovered from infested bananas preclude the use of color measurement as an indicator of risk of infestation by either fruit fly species.

Recommendations. Based on the data presented here and those of Armstrong (1983), the following five recommendations for exporting dwarf and standard Brazilian, Grand Nain, Valery, and Williams bananas from Hawaii have been developed: (1) bananas, packed as individual fingers, clusters, or combinations thereof, must be at the green stage of harvest maturity; (2) bananas must be washed and culled to exclude insect pests of quarantine importance other than fruit flies that may be present on or in the fruit; (3) bunches containing precociously ripened fingers or remaining in the plantation >1 wk past the scheduled harvest date cannot be harvested for export or be present in packing houses at the same time as bananas for export; (4) faults susceptible to fruit fly infestation, including bananas with any damage that compromises the integrity of the fruit skin and exposes the fruit flesh to fruit fly oviposition, bananas with tip rot, bananas infested with *O. sacchari,* clusters with fused fingers, and bananas not meeting mature green coloration cannot be included in packed fruit for export; and (5) the export regulatory requirements should be reevaluated for green Brazilian bananas harvested from any agricultural situation in which Mediterranean fruit fly populations exceed 500 gravid females per bunch.

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